

NANOSCIENCE AND TECHNOLOGY AT THE AIR FORCE RESEARCH LABORATORY (AFRL)



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AIR FORCE RESEARCH LABORATORY VISION

***We defend America by unleashing the
power of innovative air and space technology***



We are the Air Force Research Laboratory



Brigadier General Perry L. Lamy
Commander



Ten Directorates

Air Vehicles Directorate

Space Vehicles Directorate

Munitions Directorate

Sensors Directorate

Propulsion Directorate

Materials & Manufacturing Directorate

Directed Energy Directorate

Human Effectiveness Directorate

Information Directorate

AFOSR

Our Score Card

- 5397 government personnel
 - 4388 civilian
 - 1009 military
- 3000 on-site contractors
- \$1.3B annual S&T budget
- \$500M annual customer budget



OUTLINE



- **AN AF PERSPECTIVE OF NANOTECHNOLOGY**
- NANOSCIENCE AND TECHNOLOGY IN AFRL: PAST AND PRESENT
- A STRATEGIC PLAN FOR THE FUTURE
- SUMMARY

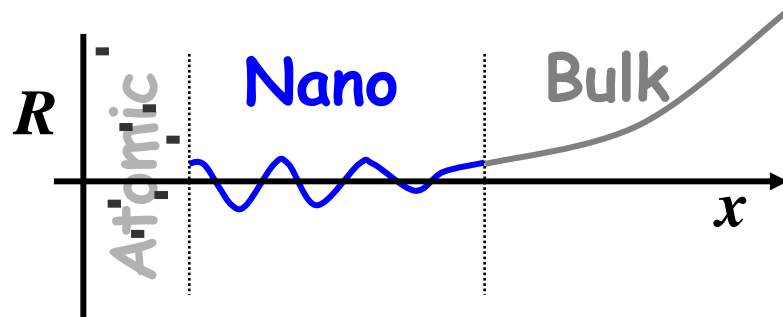


NanoScience and Technology

Defining Features



Nanoscience provides a pathway to new physical responses and behaviors



Opto-electronic

Property	Critical Length
Electron Wavelength	10-100 nm
Inelastic Mean Free Path	1-100 nm
Quantum Well	1-100 nm
Evanescent Wave Decay Length	10-1000 nm

Structural

Property	Critical Length
Defects	1-100 nm
Grain Boundary	1-10 nm
Grain Size	1-100 nm
Dislocation Interaction	1-100 nm
Crack Tip Radius	1-100 nm
Critical Nucleus	1-10 nm

Defining Features

- ❖ Provides behavior different than either bulk or atomic responses
- ❖ Characterized by non-bulk scaling or approaching a singularity
- ❖ Critical length depends upon dominant morphological length scale and property of interest
- ❖ Physical basis resides in coupling morphological dimensions with critical length scale and/or introducing high surface-to-volume ratio



Impact to Materials and Devices



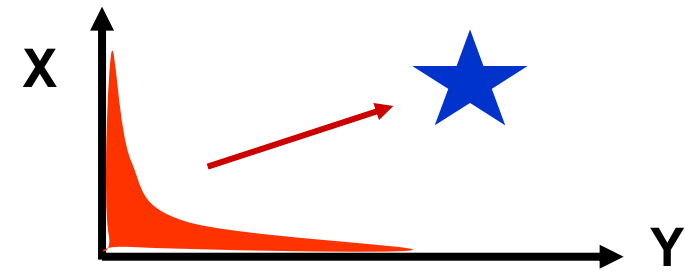
Nano-Enabled Materials

Circumvent material performance trade-offs

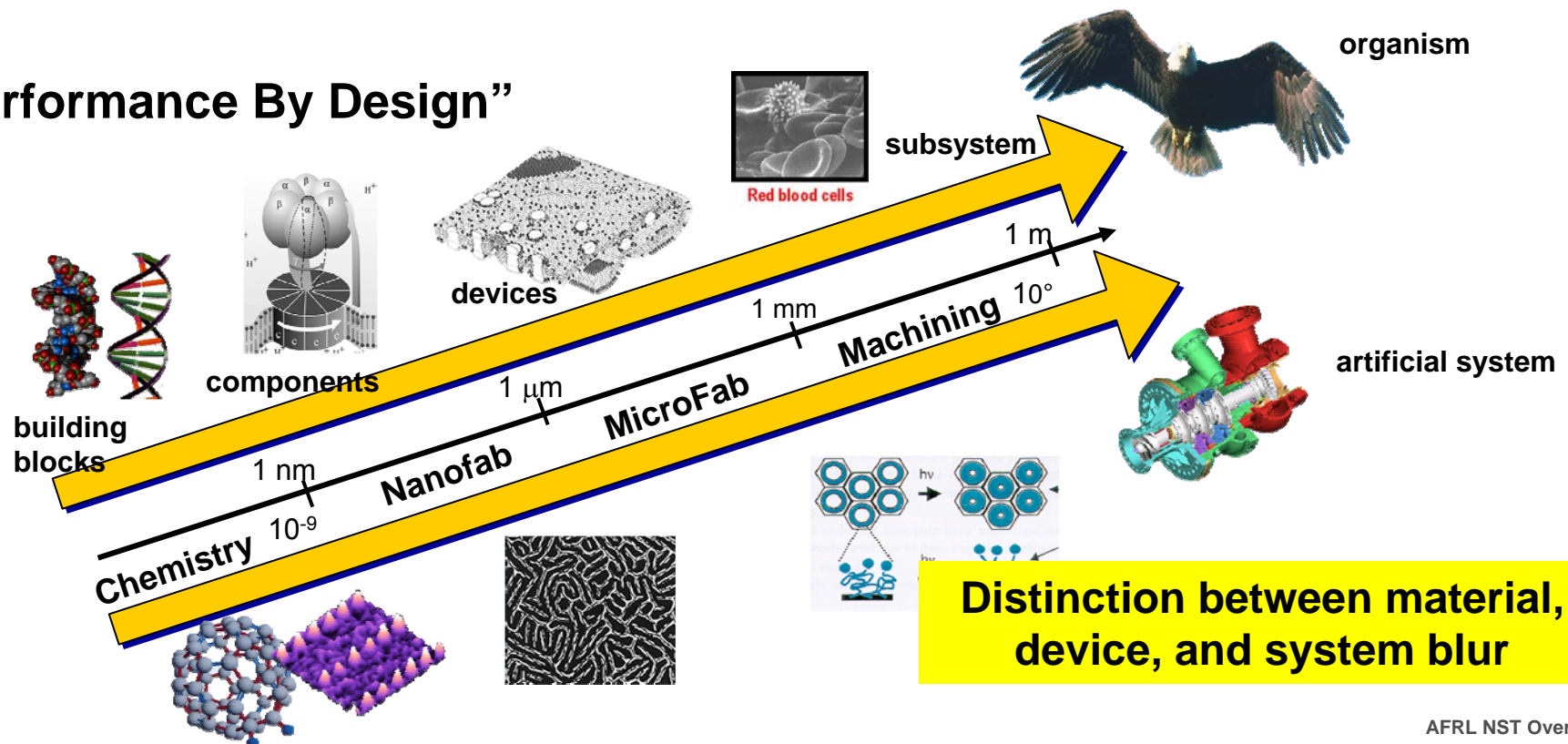
- Unique combinations

Strong
Tough
Durable

Responsive
Conductive
Optically active



“Performance By Design”





Nano-"Technology"?



Technologies Utilizing NanoStructures

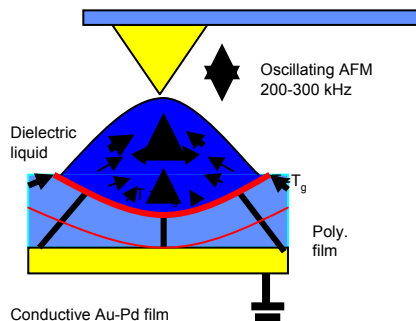
Nano-Enhanced Technologies

Coatings
Catalysts
Structures
Power Generation

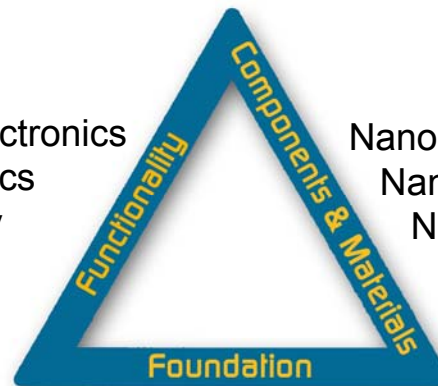
NanoMachines
NanoDevices
NanoEngineering



NanoScience



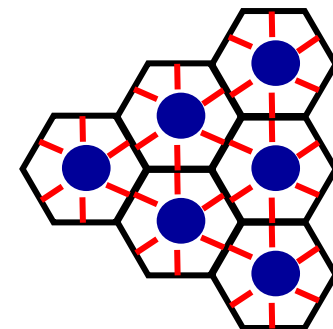
NanoElectronics
NanoMagnetics
NanoChemistry
NanoPhotonics



NanoStructures
NanoParticles
NanoComposites

NanoMetrology
NanoAssembly

NanoFabrication
Theory&Modeling





AFRL NanoScience and Technology

An Evolving Revolution



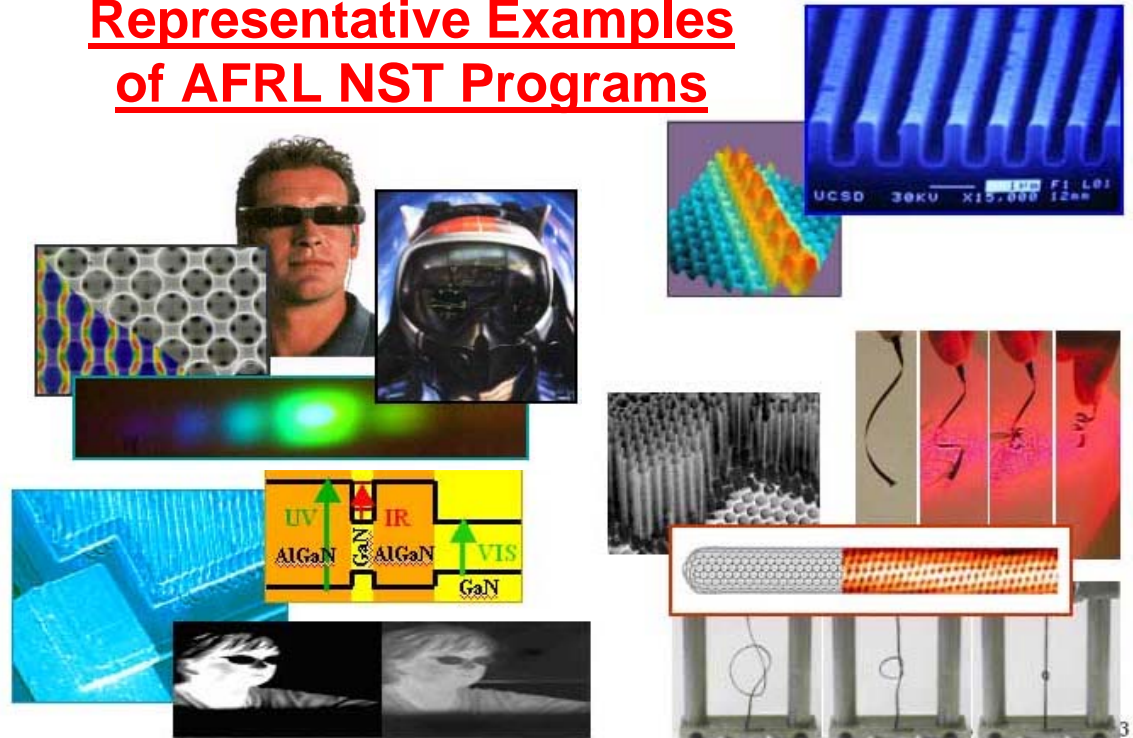
AFRL has a rich history initiating and pursuing a broad range of nanotechnology research efforts

- a natural extension of the evolving research spectrum
- focused on achieving important AF requirements

Emphasis

- **Understanding** novel phenomena, properties and functions that occur on nm length scales
- **Manipulation** of matter at the nanoscale in order to **control** properties and functions to provide enabling capabilities
- New **design**, multi-scale **integration**, and **validation** techniques to achieve macroscale functionality enabled by a nanoscale response

Representative Examples of AFRL NST Programs





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AFRL NANO R&D

An Established Foundation



ENERGY

- ✓ Advanced cathodes, anodes, batteries and capacitors (DE)
- ✓ Semiconductor phosphors and lasers (DE)
- ✓ THz lasers (DE, SN)
- ✓ Nano energetics (MN, PR)
- ✓ RF materials for groundplanes and thermal management (SN, ML, IF)

INFORMATION

- ✓ Dense, non-volatile memory and low-loss filters (AFOSR, IF)
- ✓ NEMS RF elements, picosats (IF)
- ✓ Swarm control algorithms (VS)

BIO/NANO

- ✓ Biological interactions and toxicity of nanoparticles (HE)
- ✓ Detection and neutralization of bioterrorist agents (HE)
- ✓ Bio-inspired technologies for sensing, data storage, toxin ID, warfighter monitoring and treatment (IF)

SENSORS

- ✓ Surface-enhanced detection and catalysis (AFOSR, ML, SN)
- ✓ Quantum dot detectors/emitters and multifunctional sensors (AFOSR, SN)
- ✓ Space weather sensors (VS)

MATERIALS

- ✓ Nanocomposites for multifunctional structures (AFOSR, ML, MN, PR)
- ✓ Ultrahigh temperature composites (AFOSR, ML)
- ✓ Interface science for tribology and corrosion (AFOSR, ML, PR, VA)
- ✓ Nanoscale materials for electronics (ML, PR)
- ✓ Nanotube and nanowire fabrication, assembly and characterization (ML)

STRUCTURES

- ✓ Self-healing and smart nanomaterials and structures (AFOSR, ML, PR, VA)

PROPULSION

- ✓ Nanocoatings for fuel components (PR)
- ✓ Nano electrojets (VS)

A partial list of broad nanotechnology areas historically addressed by AFRL



Advanced Detector Development



PROXIMITY INSPECTION

Small Feature Discrimination

❖ Polarization Detection in Quantum Wells

- ✓ Sub-Pixel resolution
- ✓ Contrast enhancement
- ✓ Materials discrimination

Target Status Determination

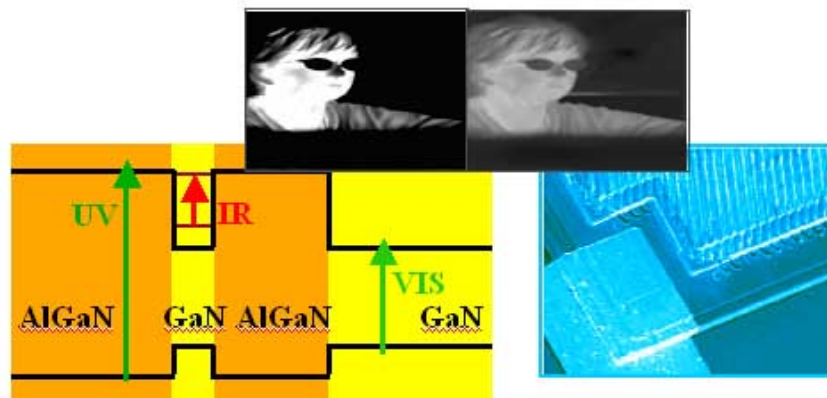
❖ Multicolor IR Detection

- ✓ Measure temperature for operational status

Small, Maneuverable Sensing Vehicle

❖ Monolithic Integration of Amplifier/ Detector/Electronics/Cooling

- ✓ Increased speed
- ✓ All wavelengths sensed with single FPA
- ✓ Volume reduced 100-1000X



LONG RANGE DETECTION

Faint Target

❖ Quantum Interference in Quantum Wells

❖ Plasmonics

- ✓ 100X fainter signals possible

❖ Frequency Agility in Quantum Wells/Dots

- ✓ Switch wavelength depending on whether sunlit or in eclipse

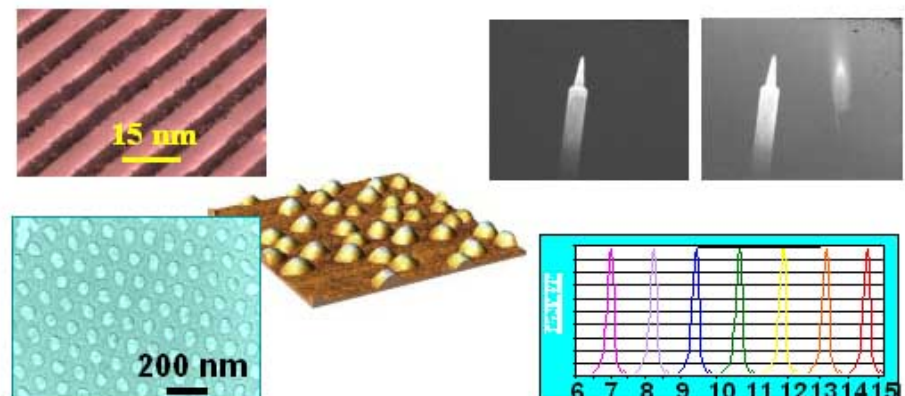
Increased Range

❖ Quantum Dots

- ✓ Reduced cooling requirements
- ✓ Optical efficiency and responsivity increases give 2-10X increased range

❖ Superlattices

- ✓ Optical efficiency and responsivity increases give 3-10X increased range



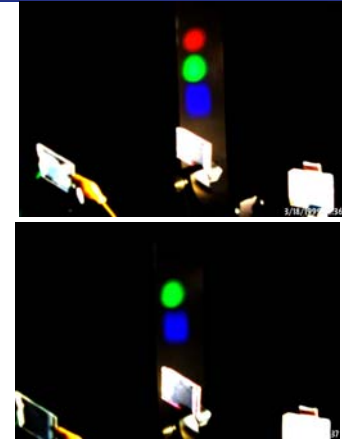
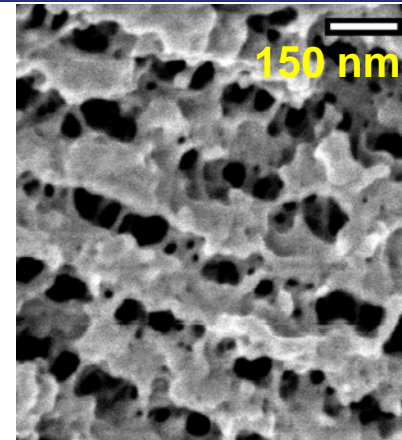


Tunable Optical Systems: Agile Optical Components



A new generation of image / information electronic displays

- Switchable photonic materials via spatially controlled nanoscale phase separation
- Switchable holographic optical elements replace bulky, immobile components

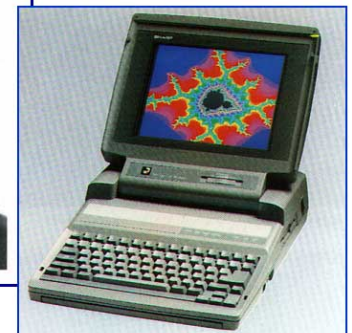


Military:

- ✓ Advanced Display Technologies
- ✓ Enhanced Imagery Support
- ✓ Helmet-Mounted Displays
- ✓ Laser Anti-Jamming Capability

Commercial:

- ✓ Telecommunication routers
- ✓ Waveguide switches
- ✓ Automatic gain control devices
- ✓ Reflective displays
- ✓ Wearable displays
- ✓ DVD/HDTV viewers
- ✓ Electronic color filters





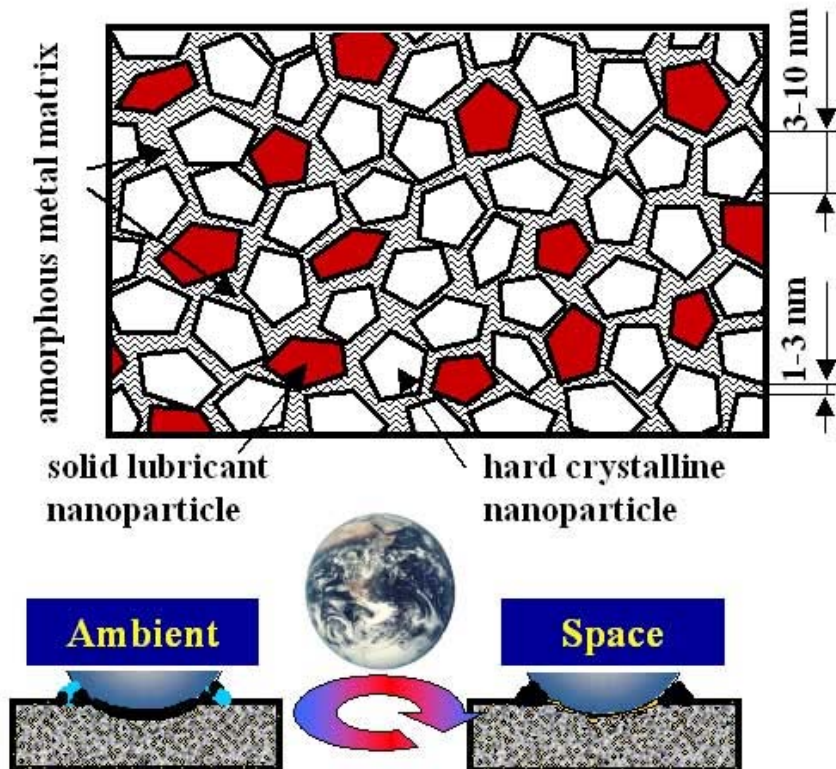
Next-Generation MultiFunctional Coatings



FRICTION AND WEAR CONTROL

Design unique nanostructured coatings

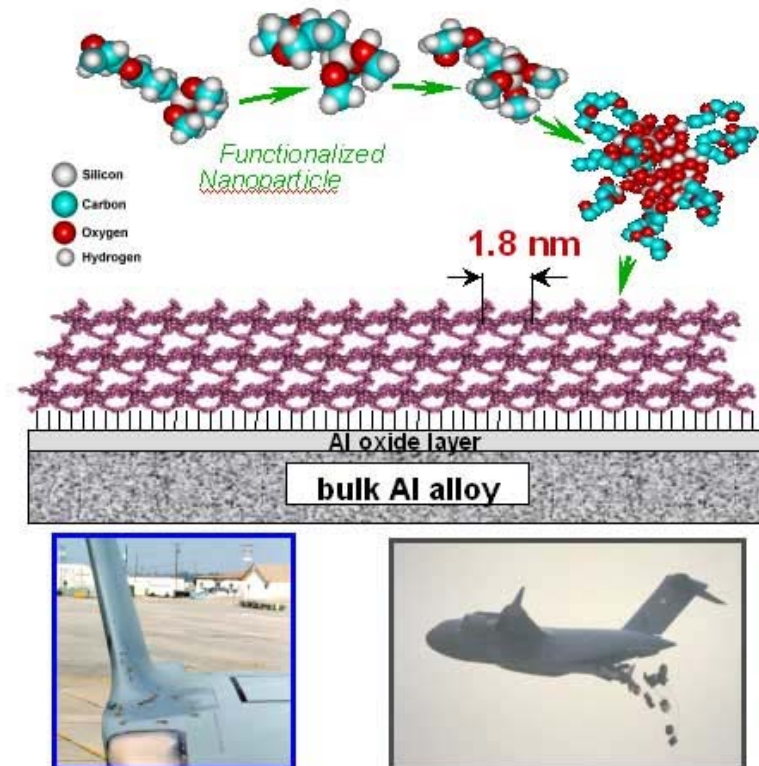
- ✓ Nano structures (layer thickness, grain size) permit unique properties
- ✓ Combine mutually exclusive properties - hardness, toughness, & low friction
- ✓ Friction and wear control in different extreme environments



CORROSION PROTECTION

Self-assembled Nanophase Particle (SNAP)

- ✓ Functionally designed new coatings - siloxane macromolecules with epoxy functionality
- ✓ Fabricate nanosized (2.4 nm dia.) siloxane macromolecules using sol-gel process
- ✓ Assemble siloxane macromolecules via amine crosslinking to form useful coating





C-Nanotube Thrust: Providing the Foundations for Applications



Fabrication
Cost, Purity,
Selectivity

Functionalization
'Handles'

Characterization & Modeling Tools

Integration
Ordered
Disordered

Applications

Sensors
Limiting
Emitters
Radar
Antennas
LO

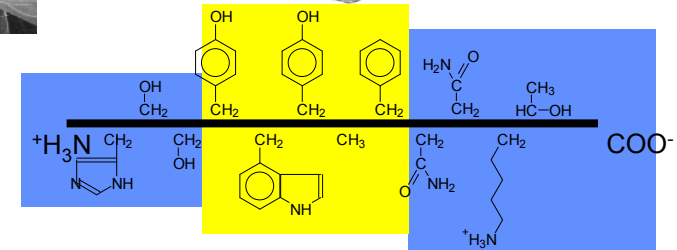
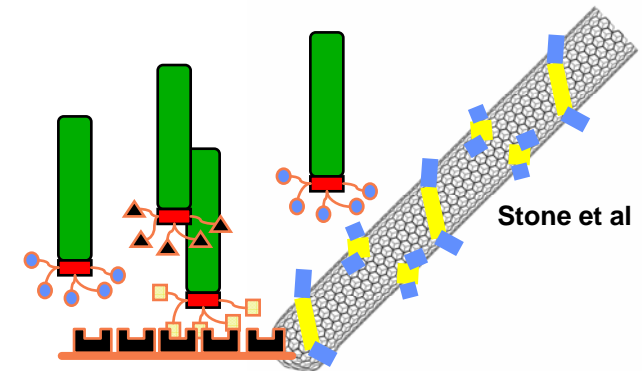
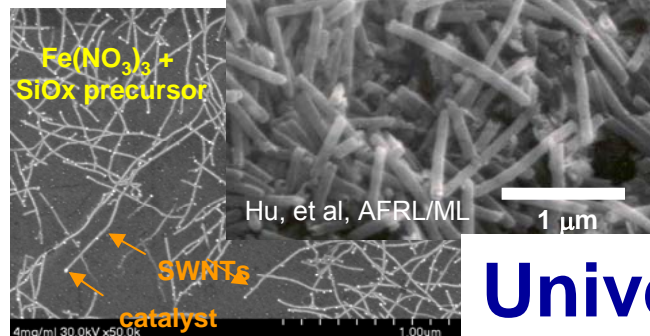
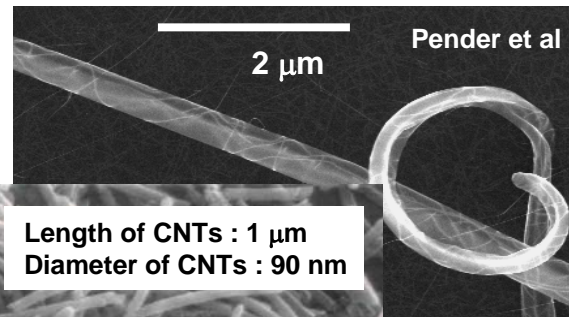
PVs
OLEDs
NLO
Thermal
Adhesives
Shape Memory
Etc..

Carbon Nanotube Cloning (R. Smalley, Rice Univ)

- Separation & Harvesting
- Cleaving
- Activation
- Re-Growth

The Tool Box

- Subsistent Chemistry
- Manufacturing
- Modeling



Universities, AFRL, Industry



Bio – Nano Interface: Assembly



Objective:

Capitalize on biology's specificity:
site, function
size chemistry
for material fabrication

Impact:

Revolutionary capabilities for bottom-up
Materials-by-design.

Approach: *Virus-like Particles (VLPs)*

Virus Particles – *ideal* nano-building block

10-200 nm Icosahedra, rod, etc.

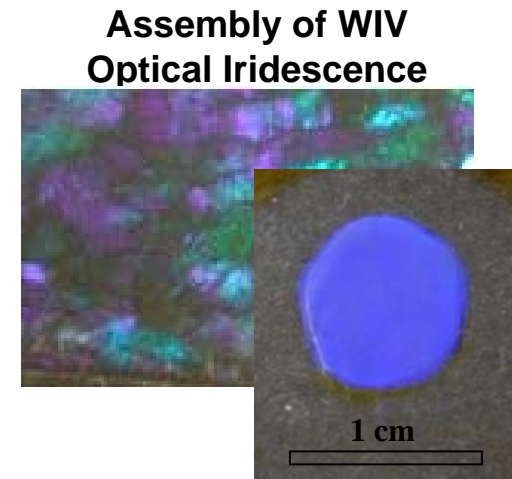
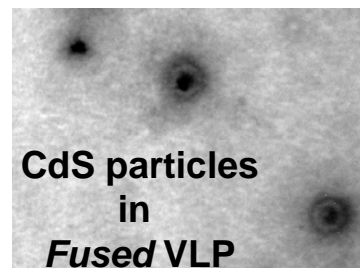
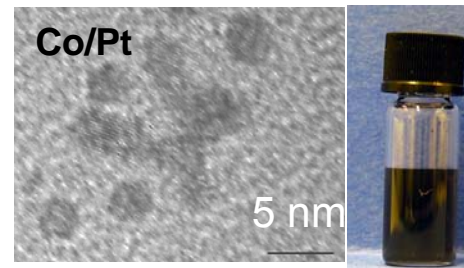
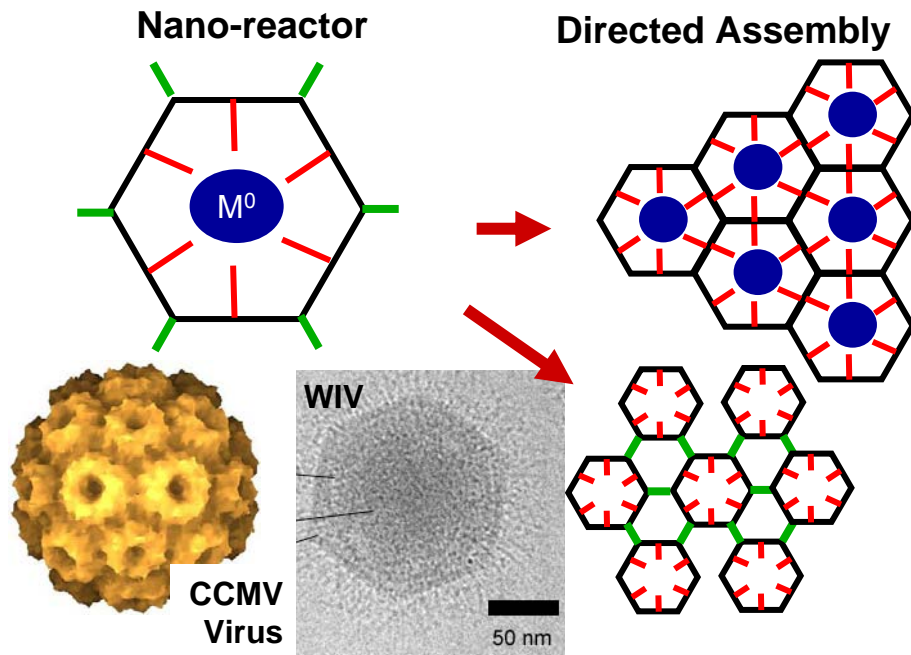
Monodisperse Functional (pH gating)

Site specific chemistry (exterior and interior)

VLPs

Self-assembly of capsid protein

Engineer protein sequence



AFOSR (BIC) Grantees
ML - CRDAs - AOARD



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AFRL NanoScience and Technology (NST) Working Group



Air Force Research Laboratory

Commander, Gen. P. Lamy
Chief Technologist, Dr. T. Cruse

NanoScience and Technology Working Group

Chair, Dr. D. Miracle
Deputy/Executive Secretary, Dr. M. Shepard

**AF Office of Scientific
Research (AFOSR)**
POC, Dr. G. Pomrenke

**Air Vehicles Directorate
(VA)**
POC, Dr. K. Ahlers

**Directed Energy
Directorate (DE)**
POC, Dr. D. Shiffler

**Human Effectiveness
Directorate (HE)**
POC, Dr. K. Geiss

**Information Directorate
(IF)**
POC, Dr. D. Burns

**Mat'ls & Manufacturing
Directorate (ML)**
POC, Dr. R. Vaia

**Munitions Directorate
(MN)**
POC, Dr. W. Cooper

**Propulsion Directorate
(PR)**
POC, Dr. C. Bunker

**Sensors Directorate
(SN)**
POC, Dr. M. Freund

**Space Vehicles
Directorate (VS)**
POC, Dr. D. Cardimona



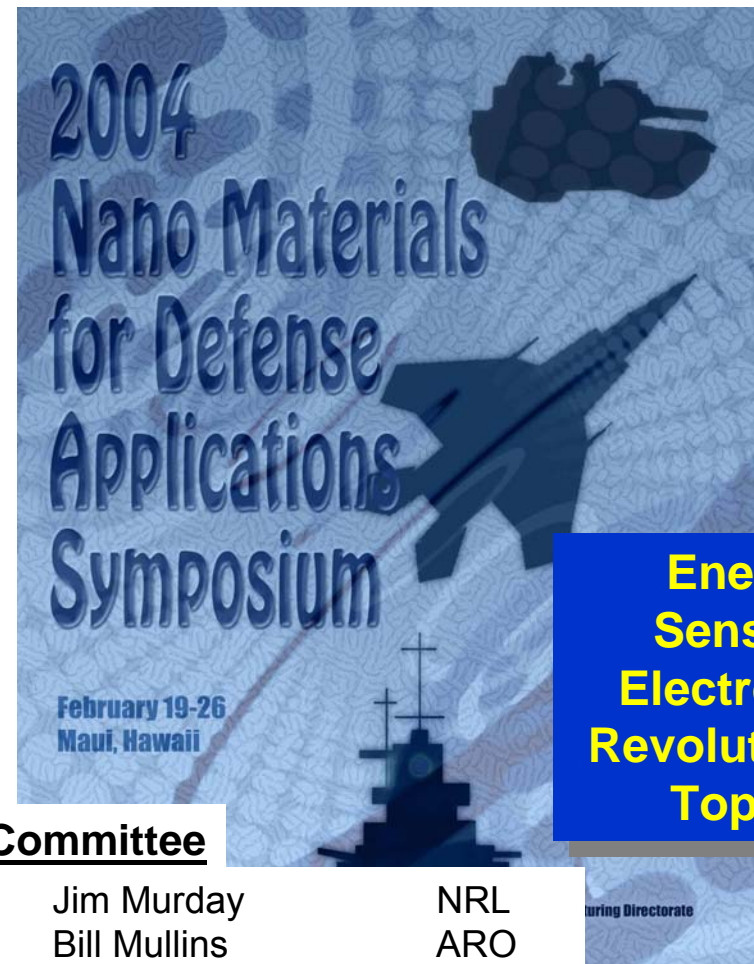
NanoMaterials for Defense Conferences



Objective: Bridge the gap between revolutionary nanoscience for materials and DoD applications, needs and drivers



**NanoEnergetics
Adv. Propulsion
Directed Energy
Revolutionary
Topics**



**Energy
Sensors
Electronics
Revolutionary
Topics**

Steering Committee

Sharon Smith
John Belk
Terry Michalske
Wade Adams

Lockheed Martin
Boeing
Sandia National Lab.
Rice University

Jim Murday
Bill Mullins
Harold Weinstock

NRL
ARO
AFOSR

uring Directorate



AFRL NST STRATEGY

Focused on AF Needs



Anticipate & determine topics most significant to the AF

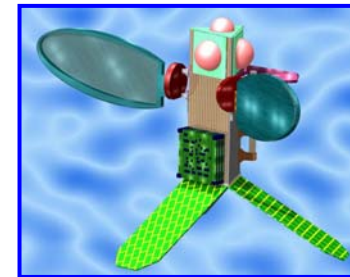
- CONOPS, AF Vision 2020, Long-Term Challenges (LTCs), Warfighter Technology Areas (WTAs), NRC study

NST topic selection criteria

- “If we don’t do it, it won’t be done.”
- cross-Directorate interactions

Examples of new capabilities:

- high-energy capacitor (2-3X) (near term)
- THz processing cube & Tb/cm² storage (near term)
- increase explosive yield by 300-500% (mid term)
- dragonfly (maneuvers, sensing, ATR, stinger) (long term)



DARPA UC Berkeley
non-flying model

Process and Outcome

- several technologist-level workshops held from 2001 to 2003 to develop AFRL-wide technical strategy
- final strategic plan approved by AFRL Corporate Board October 2003
- funding approved for 6.1 portion of the strategic plan beginning in FY06
- additional advocacy is currently underway for 6.2 investment



Nanotechnology Linkage to LTCs

Red: Included in the AFRL NST Plan



Long Term Challenges

Nanotechnology Links

Precise Finding and Tracking:

Nanosensors - multi-spectral sensing, integrated nanoelectronics and nanophotonics, high speed target acquisition & image processing, enhanced infra-red target recognition

Command and Control:

Nanodevices - Nano-processor; orders of magnitude increase in computing power, information storage, and processing abilities; radically improved decision making.

Quantum Computing - eliminate multiple design iterations and prototype testing; extremely fast image reconstruction.

Controlled Effects:

Nanoscale Energetic Materials - improved energy release rates, accelerated burn, smaller munitions, safer propellants

Nanoelectronics - Counter radiation effects

Sanctuary:

Nanosensors - airborne and space-based long range detection; multi-spectral awareness

Coatings - revolutionary dynamic stealth

Effective Aerospace Persistence:

Nanoparticles and Nanostructured Materials - advanced fuels, lubricants and additives; bearings, power generation, storage and delivery; self-healing structures; smart skins; high performance structures

Nanoelectronics - Pico-satellites, spaced-based RADAR



AFRL NST STRATEGIC PLAN

Six Selected Topics



Materials Area

1. Tailorable Dielectrics
2. Reconfigurable Optical Response
3. Adaptive Structural Materials
4. Thermal Control Materials

Energy Area

5. Energetics on the Nanoscale
6. Nano-enhanced Power Technologies

Devices Area

7. Quantum Confined Optical Sensors
8. Nanotechnology for RF
9. Nano Signal Processors

Bio-Nano Area

10. Bio Interactions of Nanostructures

Cross-Cutting (foundations)

11. Self-assembly of Nanostructures
12. Nano-Micro-Macro Interfaces
13. Modeling And Simulation

Blue: Selected topics

Red: Essential foundations



Nano Engineered Materials

Adaptive Structural Materials and Coatings



Description

- nanostructured materials with tunable mechanical properties or durability

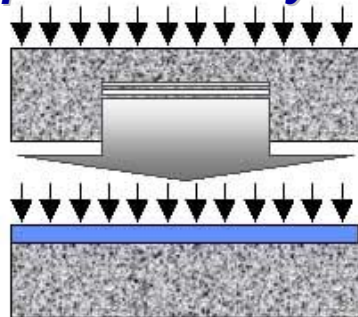
Nature of experimental demonstration

- self-passivating/repairing coatings
- airfoil warping

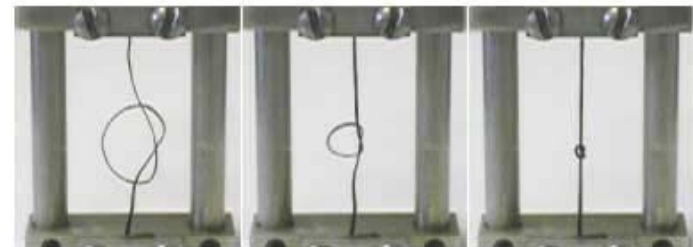
Payoff to AF- Adaptable mechanical properties enable:

- futuristic concepts of airfoil warping
- surface-directed flight control for UCAV and missiles
- self-repairing will increase service life
- actuators for space antennae deployment
- heat tolerant skin for satellites

Self-generating protective layer



Actuation



Self-adapting lubriciousness





Nano Energetics

Energetics on the Nano Scale



Description

- nano reactive materials, additives, coated powders, & laminates for munitions and propulsion
- munitions must decrease in size & require much higher lethality

Nature of experimental demonstration

- nano-propellants and nano-munitions

Payoff to AF

- munitions with 5-10x higher lethality (at same mass)
- improved propellant efficiency increases with est. \$1.5-2B/yr fuel savings
- affordable access to space via efficient propellants, high thrust/weight
- enables global strike/response

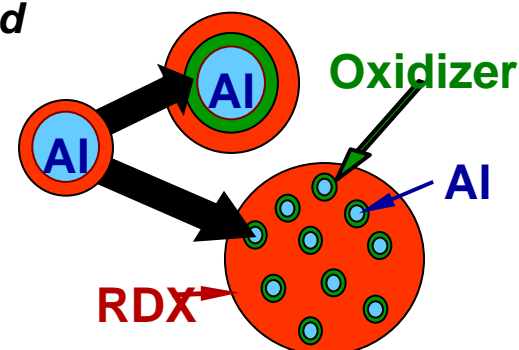


Current systems are weight-limited

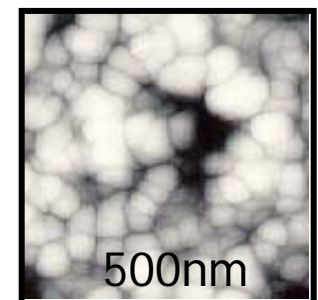
Future systems will be volume-limited



Future: Volume-Limited



Nano Al





Nano Structured Devices

Quantum Confined Optical Sensors



Description

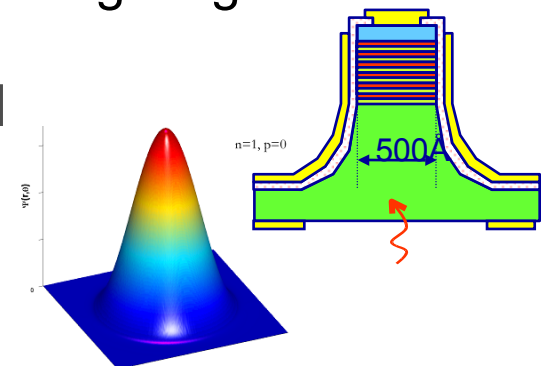
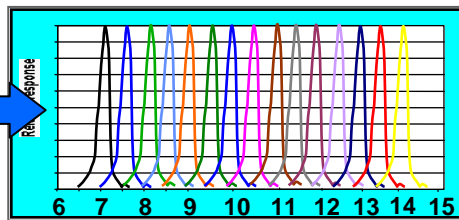
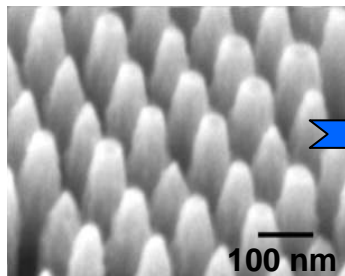
- quantum engineered materials, devices, and focal plane arrays (FPAs) for high-performance optical sensing & communication
- tailored for specific needs in UV, IR and THz

Nature of experimental demonstration

- VLWIR 256x256 FPA based on superlattices
- agile FPA based on quantum dots

Payoff to AF- New capabilities include:

- multiple narrow wavelength bands combined in a single pixel
- smart detector arrays adjust to scene conditions to optimize signal
- higher operating temperatures without sacrificing performance
- high bandwidth and secure COMM ID for tracking and targeting
- addresses multiple WTAs/LTCs/CONOPS





Nano Structured Devices

Nanotechnology for RF



Description

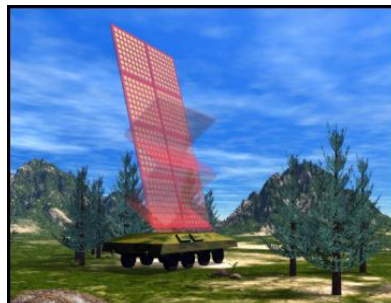
- nano-materials and nano-devices as enabling components for ubiquitous remote sensors, sensor web, and ISR for RF systems

Nature of experimental demonstration

- thermal control materials
- integrated RF system (nano-FETs, materials)

Payoff to AF- NST enables revolutionary capabilities

- nano-processors enable information dominance via high-bandwidth secure communications, microsat constellations, UCAVs, and SBR constellations
- nano-integration enables: conformal multifunctional structures (wings, etc.)
- knowledge and predictability of all forces (friend, enemy, neutral)
- persistent battlespace awareness and persistent global surveillance





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NanoScience and Technology: Challenges



Fundamental

**predictive
processing-structure-
property
relationships**

Properties
Continuum descriptions
Properties of nanoelements
Data handling

Characterization
Interconnectivity
Reproducibility
Error & defect acceptability

Technological

**integration of
new concepts and tools

identification of impact**

Infrastructure
Engineering tools
Life prediction
Life-cycle

Design paradigms
Data handling
Rapid screening
Costs benefit
Information in and out

Commercialization

producibility



Appropriate process models, quality control tools and manufacturing techniques

Extent of Process Control Required Vary with Market Size

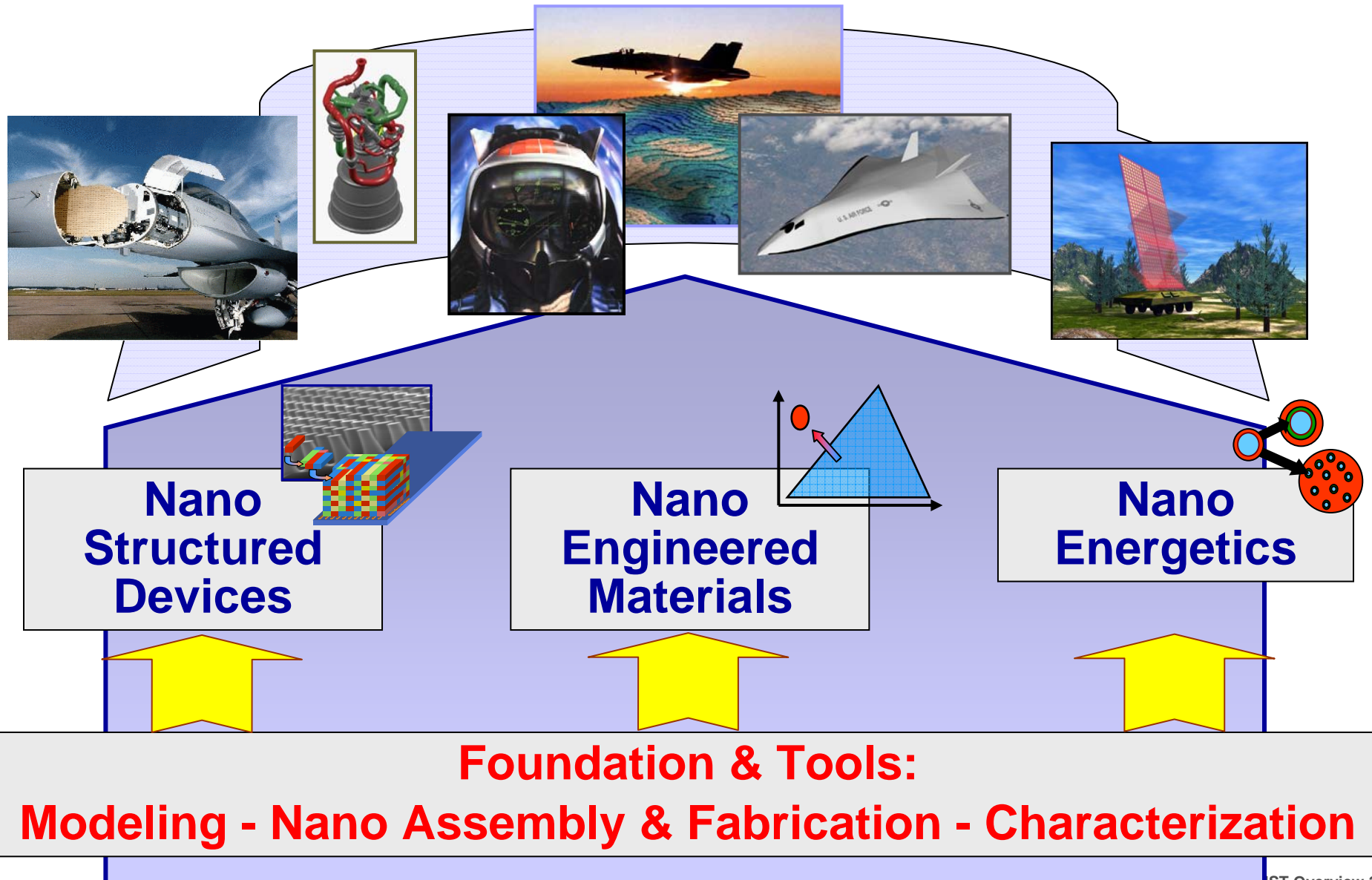
Commodity Needs, Low Volume Requirements Vs. Niche Applications

Nano —————> Tailorability —X—> Commodity



AFRL NST STRATEGIC PLAN

Focused on Achieving Warfighter Needs





SUMMARY

A large, high-resolution image of an F-35 fighter jet in flight, viewed from a low angle. The jet is dark grey and has a highly angular, stealthy design. It is flying through a blue sky with white clouds. A bright, multi-pointed starburst effect emanates from the center of the jet, creating a sense of power and advanced technology.

**AFRL generates revolutionary
technology options for the warfighter
and preempts technology surprise**



QUESTIONS?





BACKUP CHARTS



BACKUP CHARTS



NANOTECHNOLOGY AT AFRL



A tradition of excellence in aerospace R&D

- nanotechnology has been an integral part of the AFRL technology program as a natural progression of the aerospace R&D enterprise
- important advances have provided compelling AF operational capabilities

A strong strategic plan focused on AF needs

- focus areas include materials, devices and energetics

Funding has been obtained for the AFRL NST Strategic Initiative

- basic science portion funded
- effort is currently underway to obtain resources necessary to capitalize on fundamental scientific advancements



AFRL NST STRATEGIC PLAN PROCESS



Jun 01 and Aug 01: AFRL Technologist Workshops

- Purpose: Convene grass roots workshop of AFRL technologists to discuss and define a coherent and integrated AFRL NST strategy
- Representatives from each AFRL Directorate

Aug 03: AFRL NST Workshop (>60 S&T, 10 TDs, AFIT*)

- Purpose: Actionable focused & high-payoff plan
- Focus areas: Bio-nano, Energy, Devices, Materials
- First round: 42 topics
- Second round: 1-4 topics per focus area
- Result: 13 topics, 3 cross-cutting topics
- Final 6 topics selected by grading/voting

17 Sep 03: Presented to Research Council

24 Oct 03: Presentation to Corporate Board

- Accepted as official AFRL Initiative

*** AFIT: Air Force Institute of Technology**



Architects of Advanced Technology

AFRL's mission is to be the Air Force Agent for identifying and providing advanced, affordable, and integrated technologies that keep our Air Force the best in the world. Its partners and teammates include both academia and industry.

New Organization. New Mission.

Now the largest laboratory in the Department of Defense (DOD), a vital national asset, and the world's preeminent military aerospace science and technology (S&T) organization. AFRL remains dedicated to discovering and developing military-relevant technology for space, air, and command and control, and the people who operate and maintain those systems.

An essential goal of AFRL's organization is to tie the Air Force R&D mission more closely to the requirements of the warfighter. AFRL is now better aligned and more closely "tuned-in" than ever before to support the Air Force's 21st century vision of "Global Engagement." AFRL understands the critical importance of listening to what the customer wants and then providing it in a timely, cost efficient manner.

Organized for Results

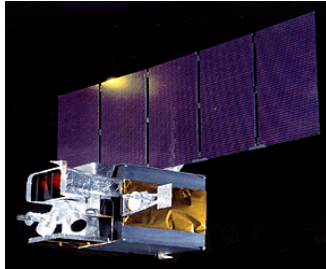
AFRL is organized along technology disciplines into nine technology directorates plus the Air Force Office of Scientific Research. Each technology directorate performs, procures, and synthesizes basic research, exploratory technology development and advanced technology development within its areas of responsibility with a clear mandate to provide integrated solutions to customer requirements.



Nano Inorganic Clusters

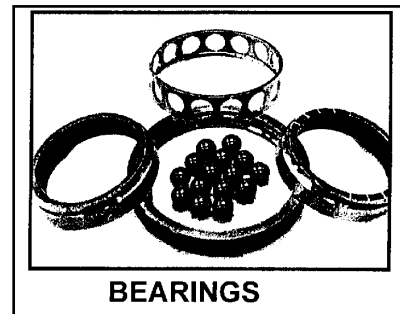


Satellites & Space Systems



- Max Space Resistance - LEO, AO, UV
- 10% Lower Density
- High Modulus
- Resins for all Structural Applications

Nanostructured Lubricants



- Current lubricants limited to 400° F
- POSS based lubricants $T_{dec} = 590^{\circ}$ F
- Desire a fluid with working temperature range of -40° to 600° F (IHPTET)

Rocket Propulsion



- Nanostructured Pulsed Plasma Fuel Additives
 - 10-20% Reduced Consumption
 - 17% Improved ISP of Current PPT
- Solid Rocket Motor Ablatives
 - cuts Insulation weight 44%
 - increases Booster Payload 7.4%

Jet Canopies



- Mach 2.x speeds limited by plastic canopy
- Target Engagement Times can be reduced by increasing flight speed



Computational Design of Nanomaterials



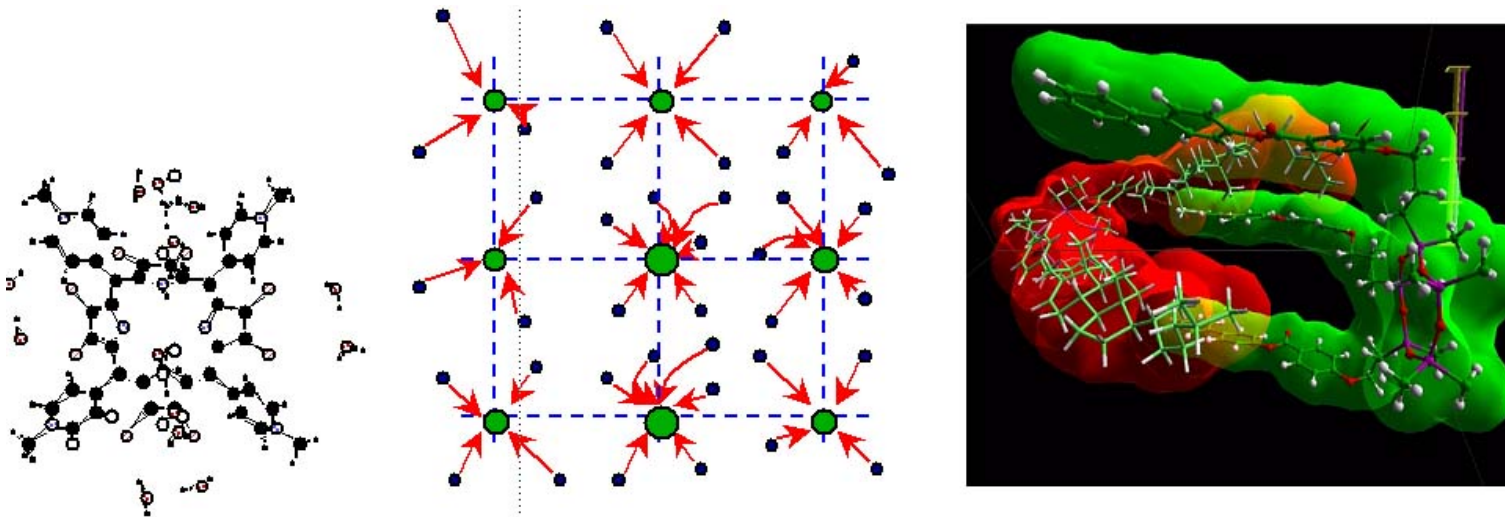
Objective: Develop and apply mathematical & computational methods to design materials at the nano-scale:

Integration of materials properties across length- and time-scales for macromolecular systems; biologically inspired materials design; complex materials, such as liquid crystals; advanced scientific computing/simulation algorithms

Success: Design of nanomaterials for Air Force applications with newly developed multiscale approaches:

Large-scale and long-time molecular dynamics using fast multipole & multi-grid methods enable simulations of liquid crystals at the nano-level; effective fragment potential method enables study of nano-optical materials in the condensed phase; newly developed optimization techniques enable large scale biomolecular structure determination

Wide-spread impact on the fundamental design of nanomaterials





NRC Study Recommendations

Red: Included in the AFRL NST Plan



NRC STUDY: HIGH INVESTMENT PRIORITY AREAS

Area	Technology Area	Current TD Priority*
Electronics H/W	Space electronics/photronics/magnetics	PR, OSR
	Nanoscale fabrication techniques	PR, ML, VA, SN, OSR
	Nanoscale materials for electronics/photronics/magnetics	PR, ML, SN, OSR
Information Processing	Data fusion	HE, IF, SN
	Distributed and autonomous systems	HE, VA, IF, SN
	Algorithms, architectures and S/W for codesign	OSR, IF
Sensors	Distributed sensors & swarms emergent behavior	VS, VA, SN
	New nanoscale materials for sensors	VS, ML, SN, OSR, HE
	EM sensors, UV to RF	ML, SN, OSR
	Hyper- and multispectral sensing	ML, SN, OSR
Structural Materials	Coatings for improved friction & wear reduction	PR, ML, OSR
	Coatings for low maintenance	ML
	Multifunctional structures for self healing	PR, ML, VA, OSR
	Multifunctional structures for Low Observable (LO)	ML
Launch Vehicle Propulsion	Nanocoatings for fuel components	PR, OSR
	Nano powder aluminum propellants	PR (ML), OSR
Manufacturing Technologies	Packaging of embedded devices	PR, VA
* Curently funded activities		



SEMICONDUCTOR QUANTUM DOTS

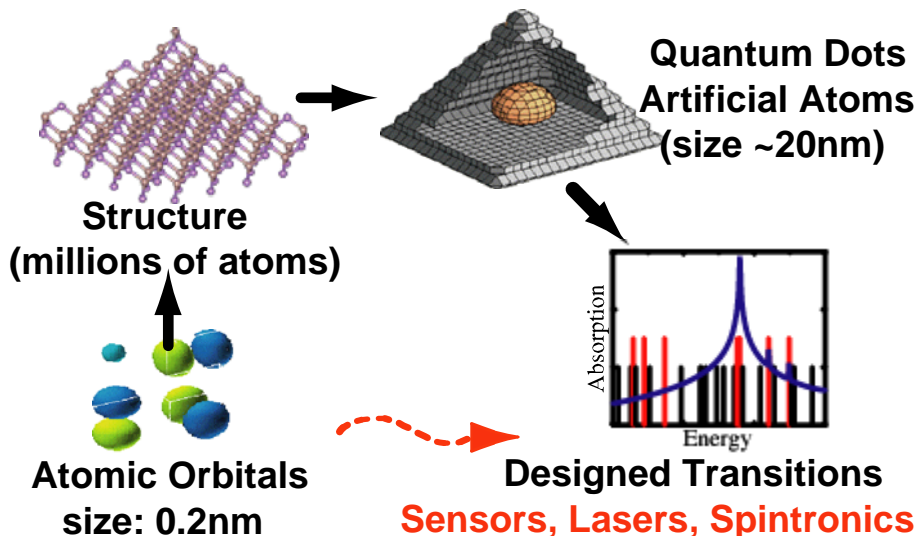


A new generation of electro-optics and sensors

- room temperature lasers and detectors at infrared wavelengths
- single electron transistors
- tera-byte quantum memory storage

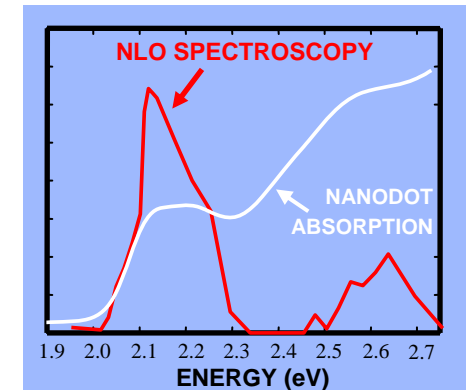
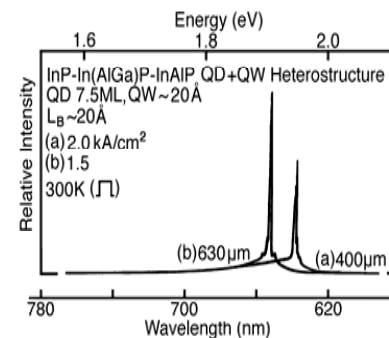
Modeling (AFRL/SN, JPL):

- ✓ atomistic description of electron structure and transport
- ✓ provides tool to accelerate material and device development



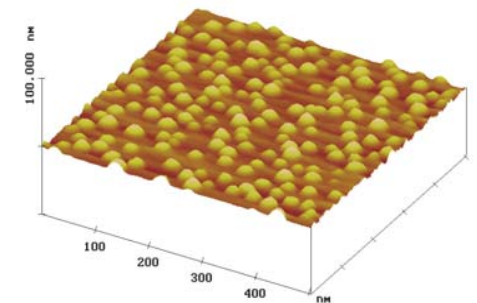
Characterization (AFRL/SN, UT Austin):

- ✓ non-linear optical quantum dot characterization



Processing (AFRL/ML):

- ✓ self-organized InGaAs quantum dots





Foundational

Objective:

Nanoscale, soft-matter (polymers, gels, biological materials) patterning tools

Impact:

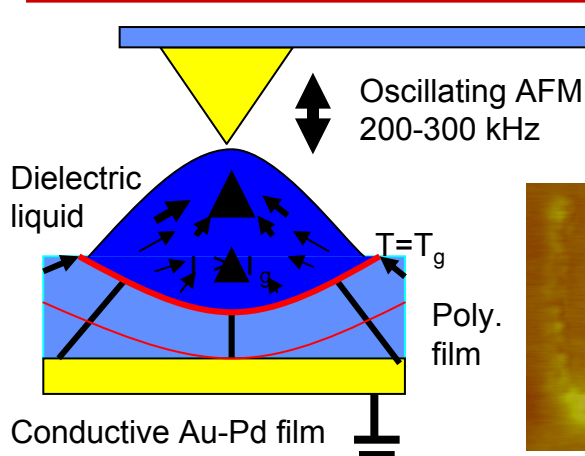
- Scientific: manipulate nanoscale phenomenon and structure
- Technological – data storage, integrated device (electronics, fluidics, mechanics) assembly

Accomplishments:

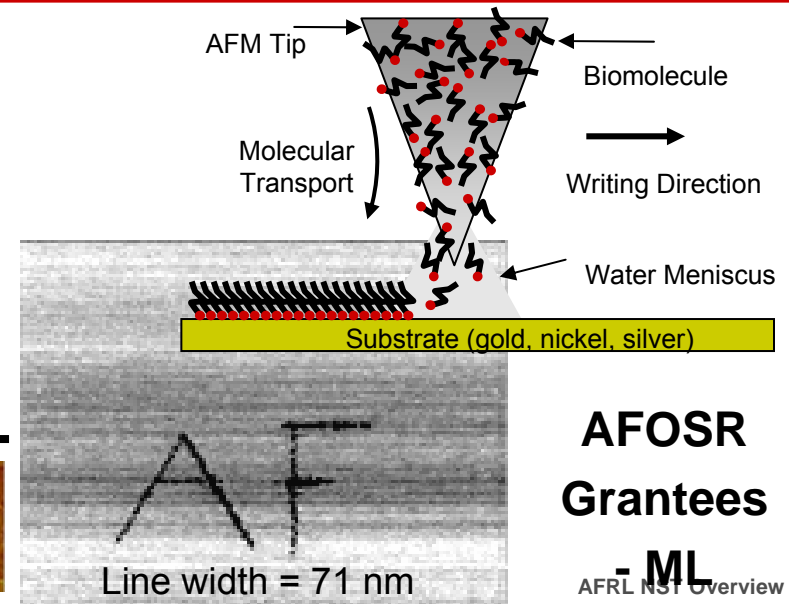
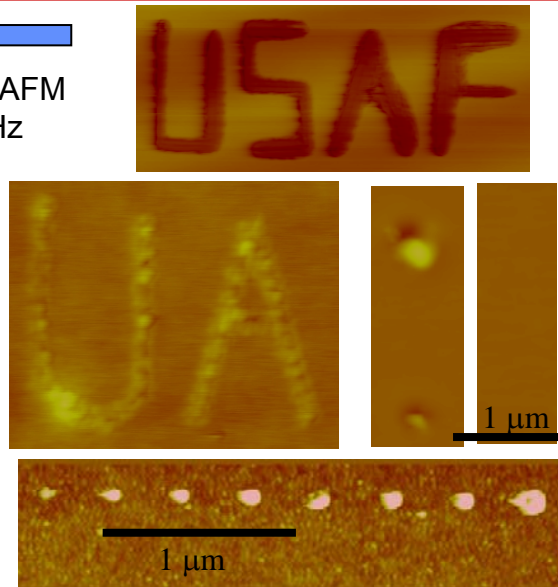
AFM Electrostatic NanoLithography (AFMEN) localized Joule heating of attoliters of polymer followed by electrostatic distortion

- 1-10 nm \uparrow , 20-50 nm \leftrightarrow
- <<msec feature generation
- ~500 Gb/in 2 ; AFM array compatible
- Rewritable

Dip-Pen Nanolithography of bio-molecules, such as catalysis peptides for inorganic



**AFOSR Grantees -
STW21 - ML**



**AFOSR
Grantees
- ML**



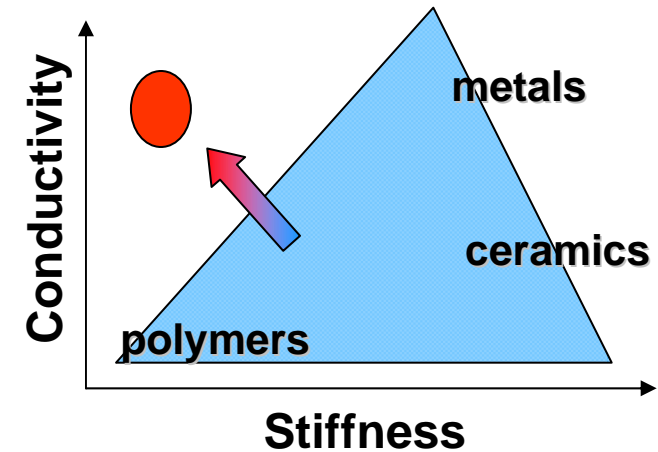
Nano Engineered Materials

Potential Return on Investment



Investments in:

- ✓ nanoengineered composites
- ✓ high-energy-density materials
- ✓ adaptive & self-healing materials
- ✓ nanostructured (nanowires, tubes, etc.) electronic/opto-electronic materials
- ✓ quantum mechanical & molecular dynamics modeling



Offer potential for:

- ✓ 10-100x stronger materials - lightweight aerospace vehicles
- ✓ 2X increase in temperature, 100X lifetime materials for turbine engines
- ✓ ability to simultaneously optimize multiple desired materials characteristics, e.g. electrical and structural characteristics
- ✓ adaptive materials - dynamic stealth and improved survivability of aerospace assets



Nano Engineered Materials

Tailorable Dielectric Susceptibility



Description

- LO and low-loss dielectrics (capacitors, RF substrates)

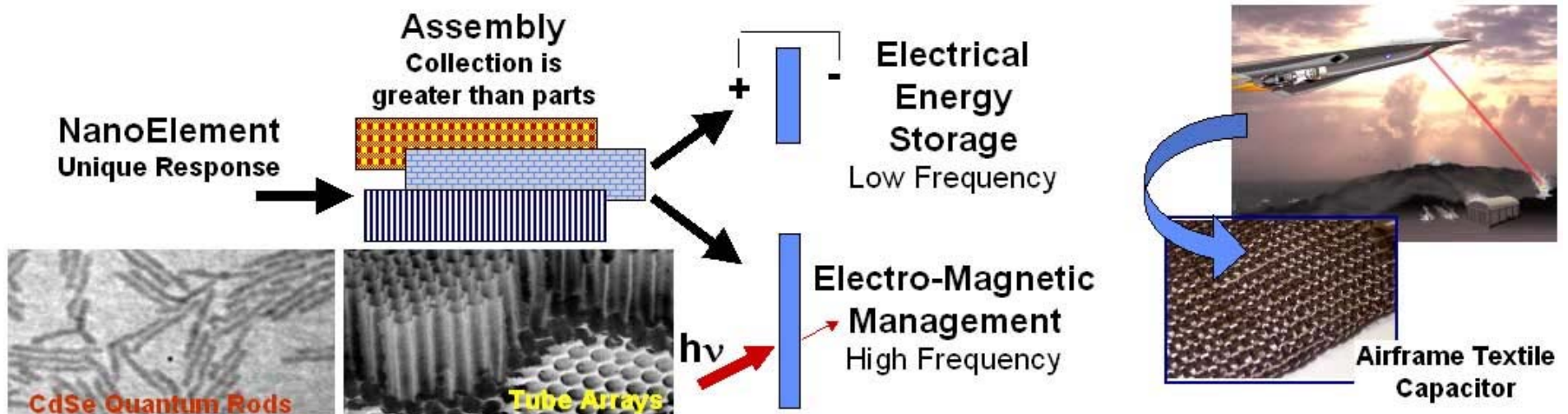
Nature of experimental demonstration

- balanced high energy capacitor
- large area panel with agile EM radiation management



Payoff to AF

- high energy capacitors for tactical lasers, satellites
- load bearing tailorable RF & μ -wave antennae for sensor craft and UCAV
- tailorable electromagnetic radiation management for new threats





Nano Engineered Materials

Reconfigurable Optical Response



Description

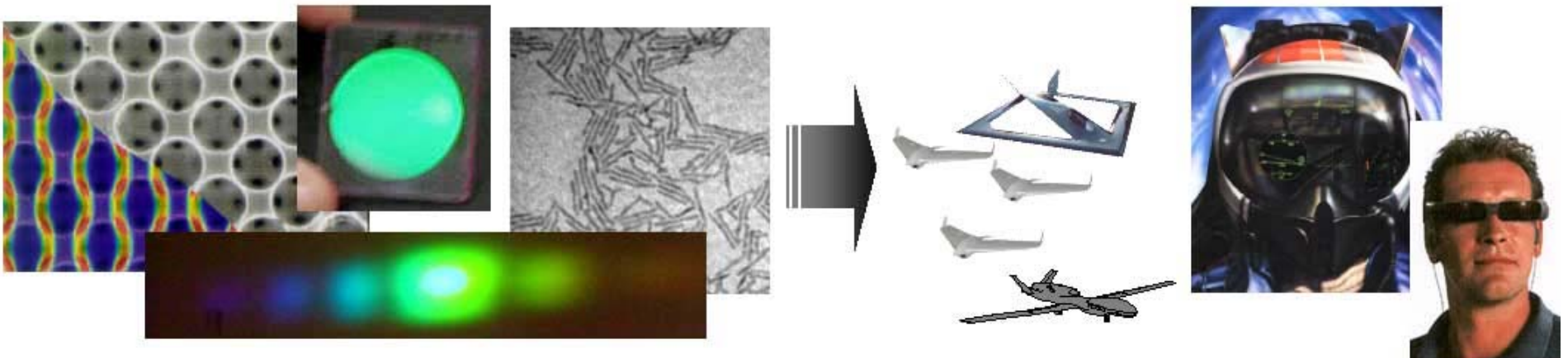
- materials that alter refractive index from thermal, electrical, or optical stimuli
- light manipulation at sub-wavelengths, photon localization, non-linear optics

Nature of experimental demonstration

- ultra-fast (ns), broad spectral (10 -100 nm) responsive optical element
- large area, low-cost optical appliqué

Payoff to AF

- enhanced system hardening for agile response to future threats
- reduce volume and increase robustness of sensor systems
- agile source/receiver for secure communication & information processing
- ultra-sensitive cavity resonators able to detect a single (or a few) molecules





Nano Energetics

Potential Return on Investment

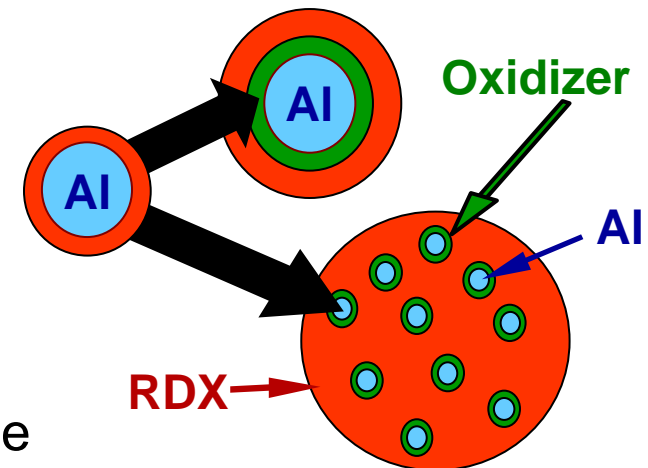


Investments in:

- ✓ nanostructured explosives and fuel additives
- ✓ nano controlled catalytics
- ✓ nano engineered photovoltaics

Offer potential for:

- ✓ 10-100x improved power density/energy release rate/ package volume and increased safety – miniature smart munitions
- ✓ improved munitions blast control – better coupling of energy to target, lower collateral damage
- ✓ stable, 5-10x more efficient propellants – safer, high-thrust-to-weight-ratio propulsion systems, increased weapon loadout, affordable access to space
- ✓ improved power generation, conditioning & control for aerospace vehicles – enhanced global reach





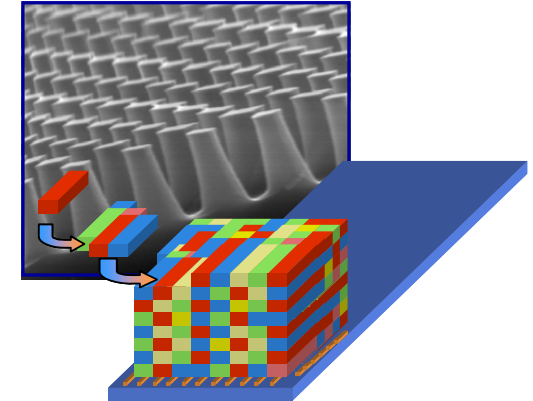
Nano Structured Devices

Potential Return on Investment



Investments in:

- ✓ nano processing/comm devices, circuits, ICs
- ✓ nano actuators, controllers, sensors, photonics & integrated NEMS
- ✓ revolutionary computing architectures – quantum, molecular, optical
- ✓ quantum communications & cryptography



Offer potential for:

- ✓ 10-1000x higher speed, lower power higher density electronics – on-board processing for target tracking/ID and autonomy
- ✓ exponential speed up for hard problem solution, e.g. scheduling, multi-asset control
- ✓ 10-1000x smaller sensors, actuators & NEMS – new surveillance capabilities, e.g. microsat constellations, UAVs, UCAVs and large, space-based membrane apertures
- ✓ high-bandwidth, secure communications - information dominance